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FLIGHT TESTS OF N.A.C.A. NOSE-SLOT COWLINGS
ON THE BFC-1 AIRPLANE

By George W. Stickle
Langley Memorial Aeronautical Laboratory

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SUMMARY

The results of flight tests of four nose-slot cowling designs with several variations in each design are presented. The tests were made in the process of developing the nose-slot cowling. The results demonstrate that a nose-slot cowling may be successfully applied to an airplane and that it utilizes the increased slipstream velocity of low-speed operation to produce increased cooling pressure across the engine. A sample design calculation using results from wind-tunnel, flight, and ground tests is given in an appendix to illustrate the design procedure.

INTRODUCTION

The first flight tests of an N.A.C.A. nose-slot cowling are described in reference 1.

The subject report presents results of four designs of nose-slot cowlings for the BFC-1 airplane in the order they were tested. The results of the tests of each cowling are presented in the following manner: (1) A discussion of the flow conditions that were desired to be changed; (2) a discussion of the alterations in the cowling that were made in an attempt to produce the desired change; (3) a discussion of the success of the alterations in producing the desired result.

Inasmuch as a cowling design for flight must first give satisfactory operation of the airplane and the engine, this factor was the primary consideration for the first two nose-slot cowlings. Most of the actual studies of flow around a nose-slot cowling were made with nose-slot cowlings 3 and 4.

Reference 2 gives the results of wind-tunnel tests of nose-slot cowlings that were conducted after these flight tests were completed. This reference gives more complete information on the effect of variables such as the radius of curvature of the nose shape, the slot location, the slot size, and the effect of engine conductivity. Some of the special problems of applying cowling design to flight work will be discussed in the present paper. Many details that do not enter the problem when making wind-tunnel tests become the determining factors of design for flight tests. Anything that impairs the operation of the engine or airplane, or that interferes with the pilot's ease of flying the airplane, must be given serious consideration by the designer of cowlings for flight. The designer must always strive to obtain a good aerodynamic design consistent with the successful operation of the airplane.

An example of a design computation along with charts to aid in its solution is given in an appendix of this report.

GENERAL APPARATUS

The airplane used for the tests was a Curtiss BFC-1 airplane shown in figure 1. It is fitted with a Wright SGR-1510 14-cylinder twin-row radial engine with a propeller gear ratio of 4:3. Two propellers were used in this investigation: the service propeller designated propeller C, Navy plan form 5868-11, which has three blades, a diameter of 9 feet 10 inches, and round blade shanks; and propeller A, drawing No. 30-1365, which has four blades, a diameter of 8 feet 6 inches, and airfoil sections carried close to the propeller hub. Engine temperatures were determined by a selective thermocouple installation. Line drawings of all the cowling variations tested are shown in figure 2.

NOSE-SLOT COWLING 1

The general lay-out of nose-slot cowling 1 is shown in figure 2. Views of cowling 1 are shown in figures 3 and 4. The cooling air for nose-slot cowling 1 entered through the baffles on the cylinder barrels and returned through the baffles on the cylinder heads. The service-head baffles were reversed to accommodate the reverse flow.

The paths of the entering and the returning air were divided at the radius corresponding to the thick reinforcing fins at the bases of the heads. It would have been much more desirable to locate the dividing wall at a larger radius but the difficulties of making an airtight seal at any larger radius determined its location. Measurements of the pressure drop across each path showed that all the measurable pressure drop occurred across the barrel baffles and practically no pressure drop occurred across the head baffles. This result was, of course, the reverse of that desired because the maximum cooling is needed on the cylinder head.* The barrel baffles were then removed to lessen the pressure drop across the barrel but, even after this alteration, there was still about three times as much pressure drop across the barrels as across the heads. A change in the cowling design was therefore necessitated in order to provide sufficient cooling for the cylinder heads.

NOSE-SLOT COWLING 2

Nose-slot cowling 2 differed from nose-slot cowling 1 in the following respects: (1) all the cooling was done on the inward passage of the air; (2) a duct over the cylinder heads returned the air to the exit slot; (3) the baffling of the engine was changed to reduce the engine conductivity; and (4) separate openings were provided for high- and low-speed operation by means of a movable portion of the nose adjustable from the cockpit.

The conductivity of the service-baffle installation was between 0.15 and 0.18, which would have required excessively large return ducts and exit openings to provide sufficient pressure drop for cooling. By the measurement

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*The fact that the engine operated in flight without failure for the condition of good barrel cooling and very little head cooling may mean that the criterion of maximum cooling on the head is wrong. It is possible that barrel cooling, especially near the head, is a more important factor than is usually supposed and, if this part is cooled sufficiently to keep the oil film between the piston and cylinder wall from failing, the engine head may be operated at much higher temperatures than is acceptable today. Research on this problem should be conducted to ascertain the truth of this indicated result.

of the space between the fins, it was found that close baffling of the cylinders would reduce this value to approximately 0.08. New baffles were therefore made in accordance with the information given in reference 3; these baffles gave a value close to that predicted. It is shown in reference 1 that the most efficient exit slot for high-speed operation opens so as to discharge the air radially at the extreme front of the cowling and that the best slot for maximum cooling for ground and low-speed flight operation discharges the air nearly axially farther back on the nose. Nose 2 combined these two features to give a cowling of maximum cooling for low-speed operation and maximum efficiency for high-speed operation. A line drawing of nose 2 is included in figure 2. Nose 2 adjusted for low speed is shown in figure 5(a) and, for high speed, in figure 5(b). Figure 5(c) shows the internal arrangement of the head baffles and the return ducts, which formed the head baffles.

The result of one ground test of this cowling is included in table I.

The averaged results of seven flight tests of the service cowling and of nose-slot cowling 2 are given as follows:

Cowling	Air speed (m.p.h.)	Cylinder-head temperature (°F.)		Average cylinder-barrel temperature (°F.)
		Average	Maximum	
Service (fig. 1)	175	454	486	273
Nose-slot:				
High-speed slot	183	413	447	240
Low-speed slot	174	400	423	230

A full-throttle climb at 104 miles per hour up to 10,000 feet showed a maximum cylinder-head temperature of 450° F.

The general operation of cowling 2 was satisfactory; it gave sufficient cooling for the ground run and the take-off and, as can be seen from the preceding table, an increase of speed of 8 miles per hour for the high-speed condition. The most interesting result for this installation, however, was the large increase in cooling obtained by rebaffling the engine. The useful cooling power was reduced from 50 horsepower for the service installation to 7 horsepower for the high-speed slot position on nose-slot cowling 2 and yet the temperatures of cylinder heads were reduced 40° F. and of the cylinder bases 30° F. This result demonstrates the importance of using close baffling on an engine. Approximately half of the increase in speed is due to the saving in the cooling power and half to the improvement of nose-slot cowling 2 over that of the service-cowling installation.

NOSE-SLOT COWLING 3

Nose-slot cowling 2 having given satisfactory operation of the airplane, it was possible to begin more detailed research on cowling operation. The first problem was to study ways and means of increasing the engine cooling to as large a value as possible. The total available pressure difference across the cowling is known to be divided between the pressure drop across the engine and the pressure drop out of the exit slot. The relationship of these pressure drops is given in reference 4 as:

$$\frac{\Delta P}{q} = \left(\frac{Q}{FV}\right)^2 \left[\frac{1}{K^2} + \frac{1}{K_2^{\,2}}\right] = \frac{\Delta p}{q} + \frac{\Delta p_2}{q} \qquad (1)$$

where ΔP is the total available pressure drop across the cowling.

q, the dynamic pressure of the air stream.

Q, the quantity of air flowing through the cowling.

F, the frontal area of the engine.

V, the air speed.

K, the engine conductivity.

K_2, the exit-slot conductivity.

Δp, the pressure drop across the engine.

Δp_2, the pressure drop out the exit slot.

Also from reference 4,

$$\frac{\Delta p}{q} = \left(\frac{Q}{KFV}\right)^2 \tag{2}$$

Substituting:

$$\frac{\Delta P}{q} = K^2 \frac{\Delta p}{q}\left[\frac{1}{K^2} + \frac{1}{{K_2}^2}\right] = \frac{\Delta p}{q}\left[1 + \left(\frac{K}{K_2}\right)^2\right]$$

$$\frac{\Delta P}{\Delta p} = 1 + \left(\frac{K}{K_2}\right)^2 \tag{3}$$

For a given engine installation (K being constant), equation (3) shows that it is necessary to make K_2 as large as possible if Δp is to be nearly equal to ΔP. In the design of nose 2, the conductivity of the exit slot was nearly equal to that of the engine so that the available Δp across the engine was one-half the total available ΔP across the cowling. In order to increase $\Delta p/\Delta P$, it was decided to increase the exit area for the low-speed condition.

Nose-slot cowling 3 was built so that the cowling nose had 1-1/2 inches of travel instead of 7/8 inch as on nose 2. (See fig. 2.) From the drawing of nose slot 3 in figure 2, it can be seen that 1-1/2 inches of travel gave a 1-1/2 inch opening for the low-speed slot and a 1-inch opening for the high-speed slot. This travel of 1-1/2 inches was the maximum obtainable because of the fixed distance between the rocker boxes and the propeller blades.

Several variations of nose-slot cowling 3 were made. (See fig. 2.) The original design was nose 3-A, which was changed as follows:

3-B: The inner lip of the low-speed slot was made larger.

3-C: A filler piece was placed behind the slot to prevent separation of flow from the cowling surface.

3-D: The outer lip of the high-speed slot was made straighter. This change decreased the travel a small amount.

3-E: The top part of the movable nose was straightened to change the direction of air flow behind the slot and a longer filler piece attached to the inner lip was placed behind the slot.

3-F: A new filler piece parallel to the propeller axis was put on. (See fig. 6.)

Before tests of nose-slot cowlings 3 were started, a 30-cell manometer was installed in the airplane to measure pressures around the cowling and across the baffles. An air-speed meter was connected to pressure tubes located in front of and behind the baffles to give the pilot a visual observation of the pressure drop. The readings on these instruments were used to compare the cowling performances for the rest of the tests. No attempt was made to stabilize the temperatures for comparison with nose-slot cowlings 1 and 2.

The condensed results of the ground tests of nose-slot cowlings 3 are included in table I. The countervanes used on nose 3-F are shown in place in figure 7. In order to prevent leakage of air out the ends of the vanes, a 2-inch annular ring was placed in front of the countervanes. This modification to the guide vanes reduced the available pressure drop for cooling on the ground from 10 pounds per square foot to 2.5 pounds per square foot. The reduction in the effective opening of the cowling probably explains some of the pressure reduction. (See reference 5.)

Kerosene vapor was used to study the flow of air over the cowling. The kerosene vapor, which has the appearance of smoke, is produced by kerosene passed through an electrically heated tube. The tube must be heated all the way to the tip because a short section of unheated tube will change the vapor back to a liquid. The vapor will burn if a flame is held in its path. If the flame is removed, however, the vapor will immediately stop burning. No trouble was experienced when the kerosene vapor was used around an airplane engine. For further details of this type of smoke generator, see reference 6.

The use of smoke-flow studies is demonstrated by the following example. Figure 8 shows the smoke that has been introduced inside cowling 3-B coming out of the slot. The thickness of the smoke stream indicates that the flow separated behind the lip of the cowling. Cowling 3-B produced only 12 pounds per square foot pressure drop for cooling with the four-blade propeller A turning at 1,860 r.p.m. (See table I.) In an attempt to prevent this breakdown of flow, a filler (cowling 3-C, fig. 2) was placed behind the slot.

Figure 9 shows the smoke flow over the outside surface of the cowling with the filler in place. A close examination of the flow just behind the slot shows that the breakaway occurs farther behind the exit, giving a 50-percent increase in the pressure drop for cooling on the ground. This fillet was expected to give unsatisfactory conditions of flow over the back part of the cowling, but the problem at the time was to determine how far back care with the design was necessary in order to obtain a good pressure drop. On another modification, cowling 3-F shown in figure 10, there is no apparent breakdown of flow, as shown by the fact that the smoke flow is nearly the same thickness all the way back on the fuselage.

A much clearer picture of the conditions of flow can be obtained when the smoke is actually watched than from an examination of photographs. The photographs, however, illustrate a useful means of studying flow conditions on the ground.

The results of the flight tests of cowling 3 are included in table II. For the flight test of cowling 3-A, data were obtained only with the low-speed slot because the oil overheated. This overheating was due to the fact that breakdown of flow over the rear lip of the low-speed slot increased the thickness of the heated layer of air over the after part of the cowling and this hot air, coming in contact with the oil radiator, so decreased its effectiveness that the cooling capacity was insufficient. A larger oil radiator in a separate nacelle was installed far enough below the cowling to be free of the heated layer of air. (See fig. 9.)

The increase in the area of the low-speed exit slot of nose-slot cowling 3 was not so effective in increasing the cooling pressure as was expected when the design was made. This ineffectiveness is due to the fact that a large slot is much more critical than a small slot. The ratio of the radius of curvature of the inner lip of the slot to the slot width should not be below a certain fixed value. For nose-slot cowling 2 with a 7/8-inch opening, the inner lip seemed to work very satisfactorily but, when the opening was increased to 1-1/2 inches, the inner-lip radius was too small and breakdown of flow occurred.

Another change incorporated in nose-slot cowling 3 was the localization of the curvature of the cowling surface near the exit slot to produce a high local velocity. It was hoped that the large negative pressure associated with high velocity would increase the available pressure drop.

Figure 11 shows the pressure distribution over nose-slot cowling 3-C for level flight. This localized high negative-pressure region for the slot in the high-speed position is shown near the low-speed-slot location (fig. 11(a)). When the low-speed slot was opened, however, the negative pressure at the slot location nearly disappeared (fig. 11(b)), which indicated a large decrease in the velocity due to the blocking of the air as it came out the slot. The higher negative pressures over orifices 11 and 12 (fig. 11(b)) do not mean that the velocity out the slot is higher than the velocity over orifice 10. The total pressure of the air stream out of the slot has been greatly reduced by the passage of the air around the engine.

NOSE-SLOT COWLING 4

Nose-slot cowling 4 was made larger in diameter than nose-slot cowling 3 to avoid the limitation of the fixed distance between the propeller and the rocker boxes. This increased diameter resulted in larger exit openings, a larger and smoother inner lip of the low-speed slot, and generally greater freedom in the design of the cowling.

Nose-slot cowlings 4-A and 4-B have three sizes of low-speed exit slots (2-1/2 inches, 3-1/4 inches, and 4 inches) obtainable by adjusting the outer lip of the high-speed slot. (See fig. 2.)

Nose-slot cowling 4-B differs from nose-slot cowling 4-A in the design of the outer lip for the high-speed slot. It was thought that this change might increase the effective diameter of the cowling opening and might thus improve the ground cooling. For nose-slot cowling 4-C, the outer lip of the high-speed slot was spring-loaded so that the high-speed slot remained closed until the movable part of the cowling had traveled within 1 inch of the back position where a stop prevented further movement of the lip. Inasmuch as the size of the low-speed slot could be varied without opening the high-speed slot, the effectiveness of slot size and slot efficiency for the low-speed-slot condition could be studied. Pictures of nose-slot cowling 4-A are shown in figures 12 to 14.

The results of the ground tests of nose-slot cowlings 4-A and 4-B are included in table I. Some increase in the available pressure for cooling on the ground was obtained with propeller C over that obtained on nose-slot cowling 3. Propeller A, which provided 27 pounds per square foot for cooling on the ground, gave the most spectacular improvement. This cooling was sufficient to allow the engine to be run indefinitely on the ground at full power. The advantage of a disk in front of the cowling is apparent, especially with propeller C.

The ratio $\Delta p/n^2D^2$ has the disadvantage of being dependent on the blade-angle setting of the propeller. The available Δp at a constant engine manifold pressure, however, is a better criterion of ground cooling. For instance, for cowling 3-F with propeller C and with countervanes, a propeller blade-angle setting of 11° at 0.75 R gave a $\Delta p/n^2D^2$ of 0.116 and a Δp of 10 pounds per square foot at zero manifold pressure. A blade-angle setting of 18° at 0.75 R gave a $\Delta p/n^2D^2$ of 0.195 and a Δp of 11 pounds per square foot at zero manifold pressure.

The results of the flight tests are included in table II. The $\Delta p/q$ in climb was increased from 0.79 for nose-slot cowling 3-F to 1.60 for nose-slot cowling 4-A. Cowling 4 is the first nose-slot cowling to give a larger $\Delta p/q$ in climb than in level flight, which shows that the increased velocity of the slipstream in climb is being used to advantage to produce a larger pressure for cooling. This fact is especially apparent for nose-slot cowling 4-B with propeller A; for this condition, the $\Delta p/q$ in climb was 2.06 and, in level flight, 1.32. The effect of a disk is negligible for the climb or the level-flight condition.

Figure 15 presents the variations of $\Delta p/q$ with cowling position for cowlings 4-B and 4-C. The two curves for level flight are not comparable in magnitude owing to the larger opening for flight 32 but the general shape of the curves is significant. The intermediate points on the curve for cowling 4-B are for the condition in which both slots were partly open. For the tests of cowling 4-C, the part of the curve from 0 to 26 turns is for the low-speed slot alone; the high-speed slot remained closed because of the spring-loaded lip. These curves can be extended to zero $\Delta p/q$ where the low-speed slot would be entirely closed, as shown by the dotted curve. This curve shows the great effectiveness of a small increase in the slot area for small slot openings and the decrease of the effectiveness as the slot opening becomes large. The change in effectiveness is especially apparent for the level-flight condition where the curve becomes almost level at the low-speed position. The same effect was found in reference 2 where it is discussed in more detail.

Figure 16 shows the variation of air speed at constant power in level flight with $\Delta p/q$ as obtained with cowling 4-C. Since all the points for both slots lie on a smooth curve, it seems that the efficiency of the slots must be approximately equal. A single adjustable slot located in the position of the low-speed slot would apparently be equally as good as a two-slot design.

CONCLUDING REMARKS

1. A practical application of the nose-slot cowling to an airplane in flight has been developed.

2. A nose-slot cowling, if properly designed, makes use of the increased velocity of the slipstream for low-speed high-power operation to produce increased cooling pressure. Values of $\Delta p/q$ of 1.60 in climb and of 1.12 in level flight were obtained for one cowling.

3. The location of the high-speed slot is not critical in regard to high-speed efficiency.

4. The design of the exit passage for large slot openings requires that the radius of the inner lip of the slot be large enough to prevent breakaway of the air flow. If breakaway occurs, the drag of the cowling is greatly increased.

5. Exhausting the cooling air from the cowling into a low-pressure high-velocity region requires that more care be exercised in the design of the cowling lines back of the slot than for a conventional N.A.C.A. cowling. Convergent cowling lines increase the angle of attack of the local air flow over the cowling surface and, if they are too convergent, will cause the cowling to be sensitive to slot

opening. On one installation in flight, breakaway occurred for large slot openings but no separation was present for small slot openings.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
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APPENDIX

DESIGN CALCULATIONS

An example of a design computation for nose-slot cowlings is presented along with curves to aid in the solution.

Given:

Engine characteristics

Power output - - - - - - - - - -	950 hp.
Indicated horsepower - - - -	1,100
Altitude - - - - - - - - - - -	0 to 10,000 ft.
Take-off power - - - - - - - -	1,100 hp.
Maximum engine diameter - -	45 in.
Rated engine speed - - - - -	2,200 r.p.m.
Propeller gear ratio - - - -	3:2
Number of cylinders - - - -	14
Engine-baffle conductivity -	0.10
Δp required for cooling at rated power and altitude -	40 lb./sq. ft.
Distance from trailing edge of the propeller at maximum pitch setting to the front of engine rocker-box covers - - - - - - -	10 in.

Diameter of oil cooler required - - - - - - - - - -	10 in.
Conductivity of oil cooler -	0.55
Indicated horsepower at 75 brake horsepower - - - - -	150

Propeller characteristics

Type of control - - - - - - -	Constant speed
Normal range of control - -	20°
Number of blades - - - - - -	3
Diameter - - - - - - - - - -	11 ft.
Blade-angle setting at top speed and rated altitude -	32° at 0.75 R
Speed at rated engine speed	1,467 r.p.m.
Blade-angle setting for full-power climb at minimum climbing speed - - - - - - -	22° at 0.75 R
Minimum blade-angle setting	15° at 0.75 R
Power absorbed at 1/2 rated speed and minimum blade-angle setting on the ground - - - - - - - - - -	75 hp.

Airplane characteristics

Top speed at rated altitude of the engine - - - - - - -	230 m.p.h.
Dynamic pressure at top speed and rated altitude -	100 lb./sq. ft.
Cruising speed - - - - - - - -	209 m.p.h.
Minimum climbing speed - - -	110 m.p.h.

Dynamic pressure for climbing speed at sea level - -	31 lb./sq. ft.
Use - - - - - - - - - - - - -	Military
Type - - - - - - - - - - -	Landplane
Location of engine - - - -	In nose of fuselage
Maximum diameter of fuselage behind engine - - - - - -	54 in.

Calculations:

Equivalent leak area of engine is

$$0.10 \times 45^2 \times \frac{\pi}{4} = 159 \text{ sq. in.}$$

Equivalent leak area of oil cooler is

$$0.55 \times 10^2 \times \frac{\pi}{4} = 43 \text{ sq. in.}$$

Additional area for ventilator duct to accessory compartment is 12 sq. in.

Total equivalent leak area is 214 sq. in.

In order to prevent excessive losses in the return ducts, it is advisable to make the area of the return ducts approximately 2-1/2 times the equivalent leak area, or

$$2.5 \times 214 = 535 \text{ sq. in.}$$

Area inside the engine diameter between the rocker boxes is approximately

$$14 \times 15 = 210 \text{ sq. in.}$$

Area required to provide space for the oil-cooler, the carburetor-air, and the accessory-compartment ventilator ducts is 135 sq. in. Area necessary to be provided outside engine diameter is

$$535 + 135 - 210 = 460 \text{ sq. in.}$$

Frontal area of the cowling F required is

$$45^2 \times \frac{\pi}{4} + 460 = 2{,}050 \text{ sq. in.} = 14.21 \text{ sq. ft.}$$

Minimum diameter of cowling is 51.2 inches. Necessary diameter of cowling to allow for structural blocking is 52 inches. Since the diameter of the fuselage behind the engine is 54 inches, the cowling diameter requirements need not be crowded. Geometric conductivity of the installation based on the cowling area is $\frac{214}{52^2 \frac{\pi}{4}} = 0.10$.

As the distance between the trailing edge of the propeller at the maximum blade-angle setting to the front of the rocker-box covers is only 10 inches, it is convenient to use the ordinates for nose 2 from reference 2 for this design. The ordinates for this design are given in the following table, where a is twice the distance from the propeller axis to the point and b is the axial distance from the leading edge of the nose to the point. The location of the slot (slot 2 of reference 2) is a = approximately 49 inches and b = 2.39 inches. The maximum diameter of the front opening is 38 inches.

Station	a (in.)	b (in.)
1	40.0	0
2	44.8	.52
3	46.6	1.04
4	48.7	2.08
5	50.2	3.12
6	51.2	4.16
7	51.8	5.20
8	52.0	6.24

The ordinates of this nose shape in fractions of the diameter A of the cowling are:

Station	a/A	b/A
1	0.769	0
2	.862	.01
3	.896	.02
4	.937	.04
5	.965	.06
6	.984	.08
7	.996	.10
8	1.000	.12

The values of the power coefficients P_c and $1/\sqrt[3]{P_c}$ for use with the data of reference 2 are next computed.

	Climb	High speed
P_c	$\dfrac{950 \times 375}{31 \times 95 \times 110} = 1.10$	$\dfrac{950 \times 375}{100 \times 95 \times 230} = 0.163$
$\dfrac{1}{\sqrt[3]{P_c}}$	0.97	1.83
q	31 lb./sq. ft.	100 lb./sq. ft.
Δp	40 lb./sq. ft.	40 lb./sq. ft.
$\Delta p/q$	1.29	0.40

From figure 17, which is a cross plot of data from reference 2,

	Climb	High speed
$\dfrac{\Delta P}{q}$	2.50	2.30
$\dfrac{\Delta p}{\Delta P}$	0.52	0.17

From figure 18, which is taken from reference 2,

$\frac{K}{A_2/F} = 0.58$	1.65
$A_2 = \frac{0.10 \times 2120}{0.58} = 365$ sq. in.	129 sq. in.
Slot opening $= \frac{365}{49\pi} = 2.4$ in.	0.84 in.

A slot opening of 2.4 inches for the climbing condition at 110 miles per hour is slightly too small owing to the smaller ratio of cowling diameter to propeller diameter of the design installation as compared with the installation of reference 2. This error, however, is not large and the air speed for climb is lower than will be usually experienced with this airplane; consequently, the computed slot opening may be used with confidence.

The ground condition presents a slightly different cooling problem. It is necessary to warm up the engine and the oil thoroughly before take-off is attempted, but too little information is available on how much cooling is necessary to prevent the overheating of some parts before other parts become warm. In order to gain some information on this subject, approximate relations of Δp and horsepower as obtained in reference 7 will be given. It was found that the Δp required for constant temperature difference varied approximately as the (indicated horsepower)$^{1.75}$ for the engine in reference 7. If this same relationship is used and it is desired to know how much Δp will be required at one-half the rated engine speed and the power absorbed by the propeller at this speed for the lowest blade angle and ground condition, there is obtained

$$\Delta p = \Delta p_1 \left(\frac{\text{i.hp.}}{\text{i.hp.}_1}\right)^{1.75} = 40 \times \left(\frac{150}{1100}\right)^{1.75} = 1.2 \text{ lb./sq. ft.}$$

This procedure extrapolates the relationship given in reference 7 far below the tested range but it gives some indication of the amount of Δp required.

The Δp available for this installation will now be roughly estimated.

Figure 19 shows the $\Delta p/n^2D^2$ obtained for nose 2, slot 2 with a 4-1/2 inch axial movement of the slot and a propeller similar to the design propeller at a blade-angle setting of 20° at 0.75 R as a function of the cowling conductivity. For a conductivity of 0.10, $\Delta p/n^2D^2$ = 0.000077.

From table I, the addition of a disk increased the value of $\Delta p/n^2D^2$ approximately 50 percent, giving a value of $\Delta p/n^2D^2$ of 0.000116. This value applies to a ratio of cowling opening to propeller diameter of 0.292. The maximum value obtainable for the present investigation is 38 inches/132 inches = 0.288. These values are so close that the discrepancy may be neglected.

In order to correct $\Delta p/n^2D^2$ for a decrease in the blade-angle setting from 20° to 15°, reference is made to figure 4 of reference 5. This figure shows a reduction in $\Delta p/n^2D^2$ of approximately 10 percent. The corrected value is then

$$\frac{\Delta p}{n^2D^2} = 0.00010$$

or

$$\Delta p = 0.00010 \times 12.2^2 \times 11^2 = 1.8 \text{ lb./sq. ft.}$$

This result indicates that satisfactory cooling would be obtained on the ground.

It is usually easier to measure this Δp at full engine speed on the ground, which would give a value four times as great, or approximately 7 pounds per square foot.

The size of the disk to be used on this installation is obtained as follows:

Total area of front opening is $38^2 \times \frac{\pi}{4} = 1,130$ sq. in.

Free area required is 2.5 times the equivalent leak area of the engine, $0.10 \times 45^2 \times \frac{\pi}{4} \times 2.5 = 400$ sq.in.

Area required for openings of oil-cooler, carburetor-air, and accessory-compartment ventilating duct is 135 sq. in.

Area of disk is 1,130 - 400 - 135 = 595 sq. in.

Diameter of disk is 27 in.

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GROUND TESTS

Cowl-ing	Pro-pel-ler	Number of blades	Diameter (ft.)	(in.)	Blade-angle setting at 0.75R (deg.)	$\frac{\Delta P}{n^2 D^2}$	Propeller speed at zero engine manometer pressure (r.p.m.)	Δp at zero engine manometer pressure (lb./sq.in.)	Slot position	Remarks
2	C	3	9	10	26.1	0.150×10^{-8}	1,120	5	-	
3-B	A	4	8	6	14	.174	1,860	12	-	
3-C	A	4	8	6	14	.260	1,860	18	-	
3-C	C	3	9	10	11	.061	1,800	5	-	
3-D	A	4	8	6	28	.364	1,310	13	-	
3-E	C	3	9	10	26.1	.152	1,120	5	-	
3-F	C	3	9	10	26.1	.286	1,120	9	-	
3-F	C	3	9	10	11	.038	1,800	3	-	
3-F	C	3	9	10	11	.116	1,800	10	-	With countervanes.
3-F	C	3	9	10	11	.029	1,800	2.5	-	With countervanes and 2-in. flat ring.
3-F	C	3	9	10	18	.195	1,450	11	-	With countervanes.
4-A	C	3	9	10	23	.250	1,160	9	Back	Round-edge disk.
4-A	C	3	9	10	23	.306	1,160	11	Mid	Do.
4-A	C	3	9	10	23	.388	1,160	14	Forward	Do.
4-A	C	3	9	10	23	.166	1,160	6	Back	
4-A	C	3	9	10	23	.194	1,160	7	Mid	
4-A	C	3	9	10	23	.250	1,160	9	Forward	
4-B	C	3	9	10	23	.221	1,160	8	Back	Round-edge disk.
4-B	C	3	9	10	23	.306	1,160	11	Mid	Do.
4-B	A	4	8	6	28	.903	1,310	31	- do -	Do.
4-B	A	4	8	6	28	.787	1,310	27	- do -	

TABLE II

FLIGHT TESTS

Flight	Cowling	Pro-pel-ler	Blade-angle setting at 0.75R (deg.)	Slot location	Slot position	Attitude of airplane	q (lb./sq.in.)	Δp/q	Remarks
13	3-A	C	23	-	Low speed	Level	36	0.58	
14	3-B	C	23	-	- do -	- do -	48	.59	
14	3-B	C	23	-	High speed	- do -	49	.23	
15	3-C	C	23	-	Low speed	- do -	68	.60	
15	3-C	C	23	-	High speed	- do -	68	.31	
15	3-C	C	23	-	Low speed	- do -	30	.66	
15	3-C	C	23	-	High speed	- do -	30	.31	
17	3-D	A	28	-	Low speed	Climb	28	.73	
17	3-D	A	28	-	- do -	Level	56	.72	
17	3-D	A	28	-	High speed	- do -	56	.21	
17	3-D	A	28	-	Low speed	- do -	28	.75	
17	3-D	A	28	-	High speed	- do -	28	.24	
18	3-F	C	26.1	-	Low speed	Climb	28	.79	
18	3-F	C	26.1	-	- do -	Level	45	.83	
20	4-A	C	23	Middle	- do -	Climb	28	1.49	Square-edge disk.
20	4-A	C	23	- do -	- do -	Level	67	1.11	Do.
20	4-A	C	23	- do -	High speed	- do -	79	.46	Do.
21	4-A	C	23	- do -	Low speed	Climb	28	1.49	Round-edge disk.
21	4-A	C	23	- do -	- do -	Level	68	1.19	Do.
21	4-A	C	23	- do -	High speed	- do -	80	.59	Do.
22	4-A	C	23	Forward	Low speed	Climb	28	1.60	
22	4-A	C	23	- do -	- do -	Level	67	1.12	Round-edge disk.
22	4-A	C	23	- do -	High speed	- do -	83	.37	Do.
23	4-A	C	23	Back	Low speed	Climb	28	1.44	Do.
23	4-A	C	23	- do -	- do -	Level	72	1.12	Do.
23	4-A	C	23	- do -	High speed	- do -	79	.37	Do.
24	4-A	C	23	- do -	Low speed	Climb	28	1.31	
24	4-A	C	23	- do -	- do -	Level	66	1.09	
24	4-A	C	23	- do -	High speed	- do -	80	.30	
25	4-A	C	23	Middle	Low speed	Climb	28	1.49	
25	4-A	C	23	- do -	- do -	Level	66	1.15	
25	4-A	C	23	- do -	High speed	- do -	75	.49	
26	4-A	C	23	Forward	Low speed	Climb	28	1.57	
26	4-A	C	23	- do -	- do -	Level	65	1.21	
26	4-A	C	23	- do -	High speed	- do -	75	.62	
29	4-B	C	23	Back	Low speed	Climb	28	1.28	Round-edge disk.
29	4-B	C	23	- do -	- do -	Level	65	1.08	Do.
29	4-B	C	23	- do -	10 T	- do -	67	.92	Do.
29	4-B	C	23	- do -	20 T	- do -	70	.78	Do.
29	4-B	C	23	- do -	High speed	- do -	72	.71	Do.
30	4-B	A	28	Middle	Low speed	Climb	28	2.06	Do.
30	4-B	A	28	- do -	- do -	Level	66	1.32	Do.
30	4-B	A	28	- do -	High speed	- do -	77	.85	Do.
31	4-B	A	28	- do -	Low speed	Climb	28	1.93	
31	4-B	A	28	- do -	- do -	Level	65	1.32	
31	4-B	A	28	- do -	High speed	- do -	76	.72	
32	4-C	C	23	-	Low speed	Climb	28	1.49	
32	4-C	C	23	-	10 T	- do -	28	1.36	
32	4-C	C	23	-	20 T	- do -	28	1.19	
32	4-C	C	23	-	26 T	- do -	28	.89	
32	4-C	C	23	-	Low speed	Level	64	1.16	
32	4-C	C	23	-	10 T	- do -	66	1.10	
32	4-C	C	23	-	20 T	- do -	66	1.00	
32	4-C	C	23	-	26 T	- do -	71	.85	
32	4-C	C	23	-	High speed	- do -	75	.67	
32	4-C	C	23	-	- do -	- do -	31	.71	

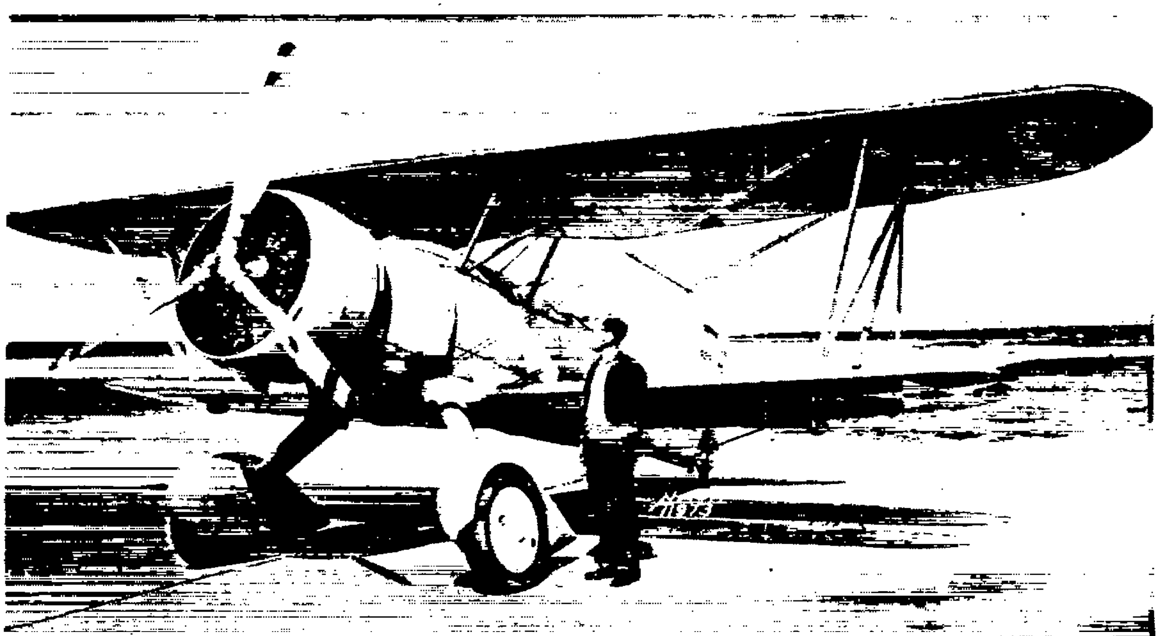


Figure 1.- Original cowling installation on the BFC-1 airplane.

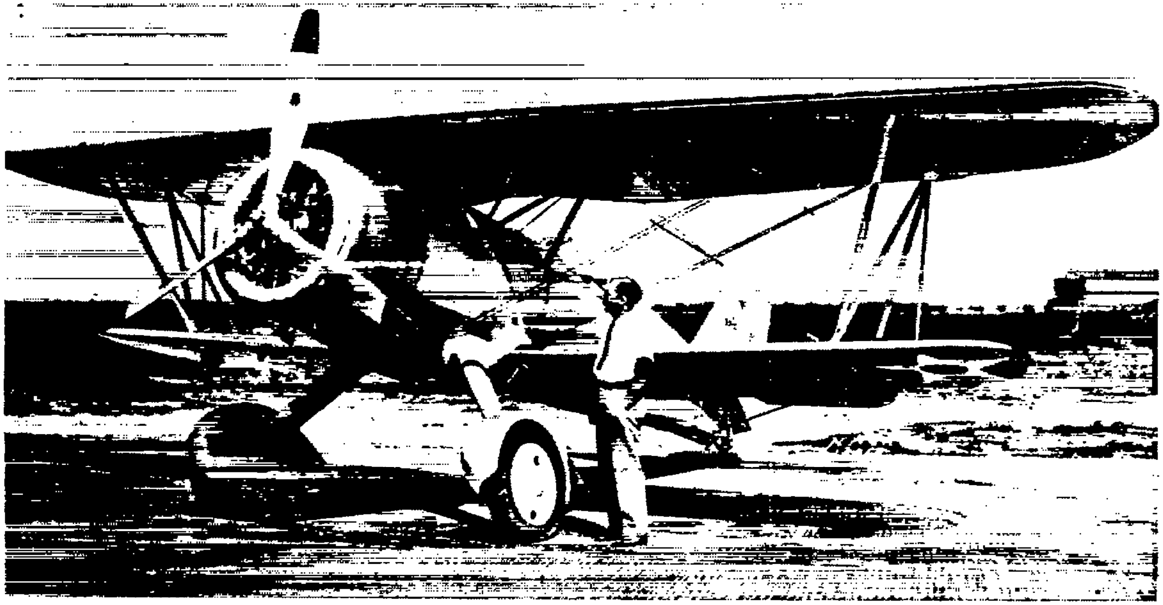


Figure 3.- The BFC-1 airplane equipped with nose-slot cowling 1.

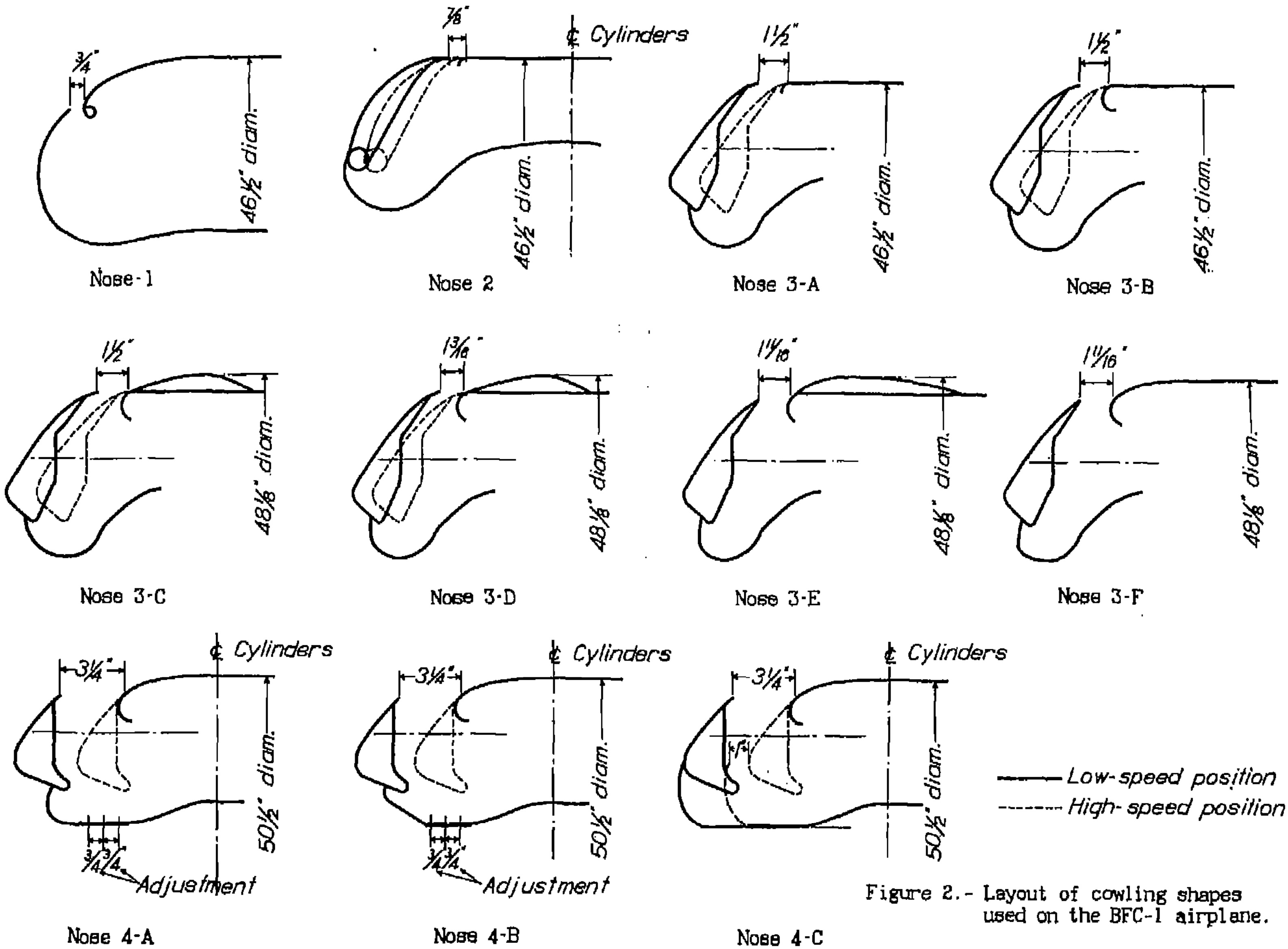


Figure 2.- Layout of cowling shapes used on the BFC-1 airplane.

Figure 4.- Close-up of nose-slot cowling 1.

Figure 5a.- Close-up of nose-slot cowling 2. Adjusted for low speed.

Figure 5b.- Close-up of nose-slot cowling 2. Adjusted for high speed.

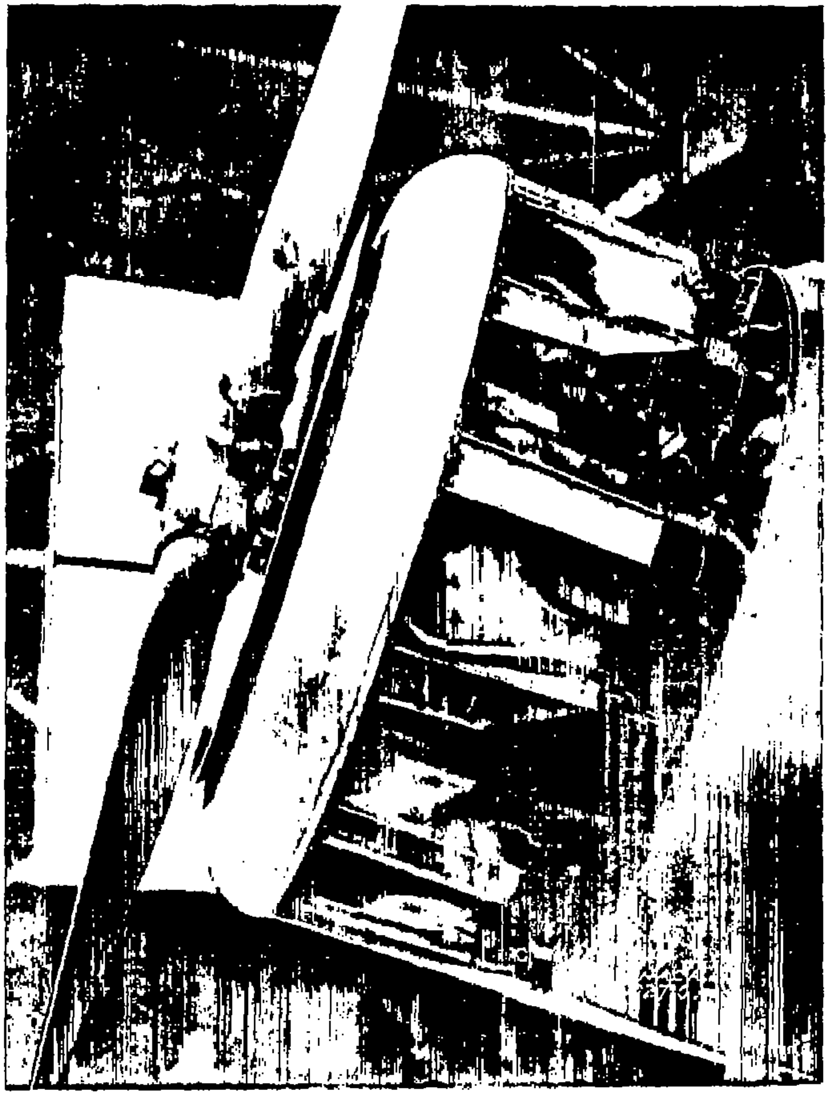


Figure 5c.- Close-up of nose-slot cowling 2. Ring removed to show internal arrangement.

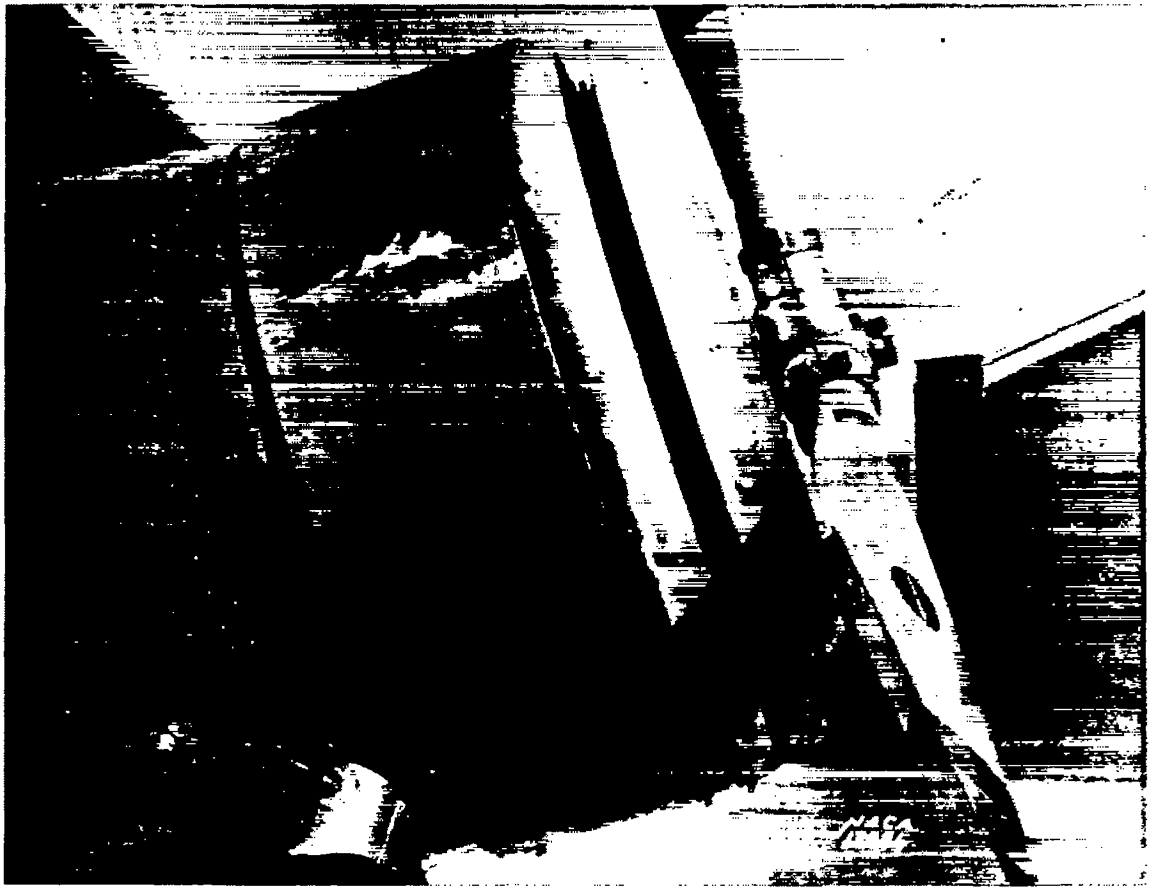


Figure 6.- Close-up of the nose-slot cowling 3-F in the low-speed position.

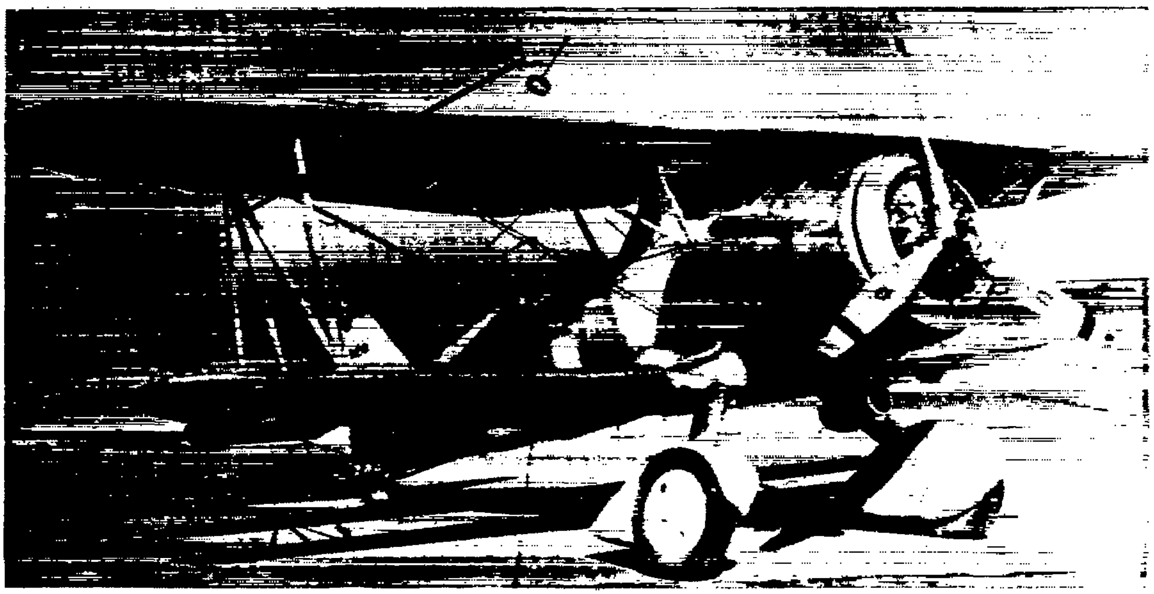


Figure 7.- Nose-slot cowling 3-F with countervanes in place on the BFC-1 airplane.

Figure 8.- Smoke flow coming out of the slot. Nose-slot cowling 3-B.

Figure 10.- Smoke flow over nose-slot cowling 3-F.

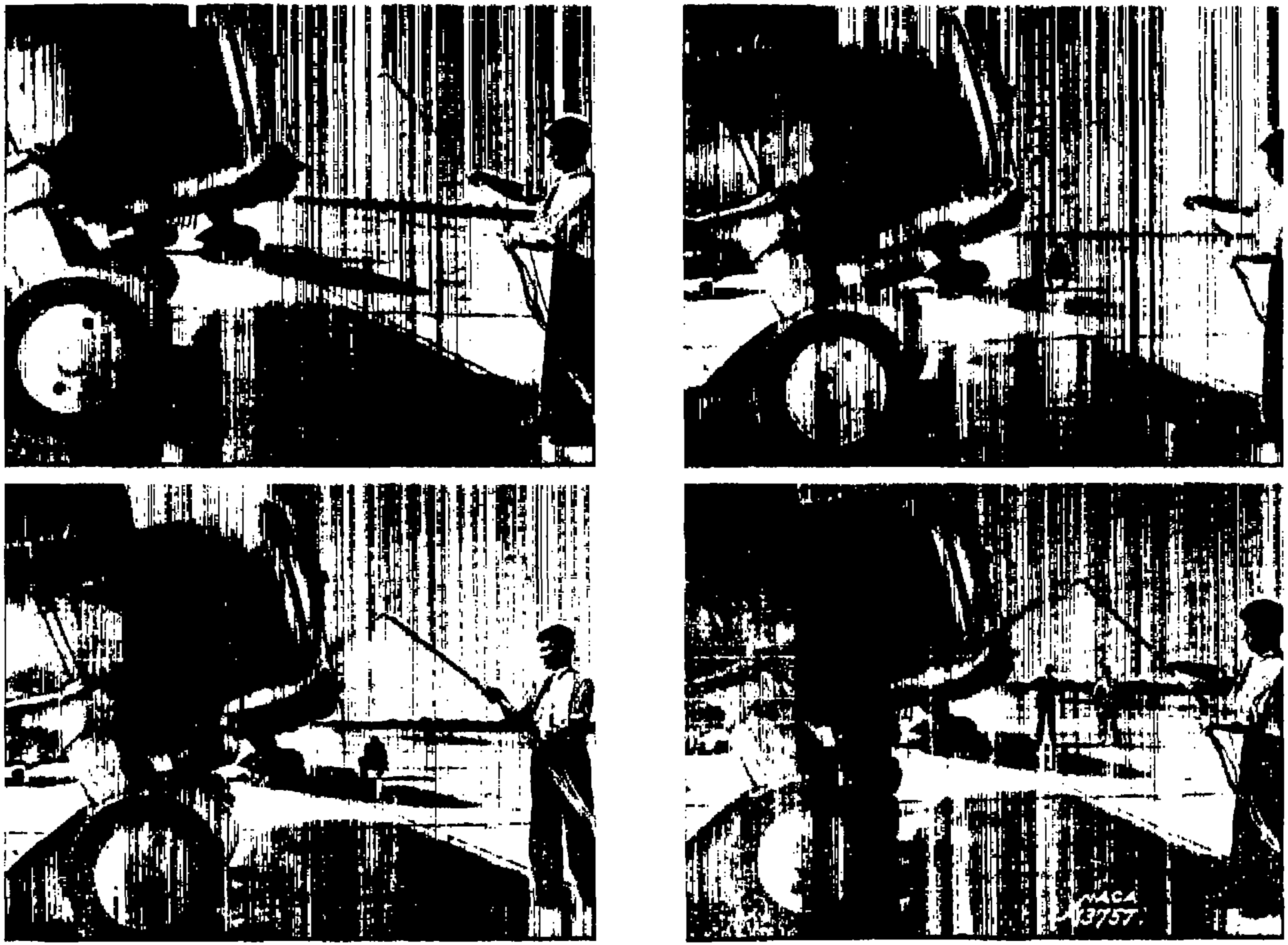
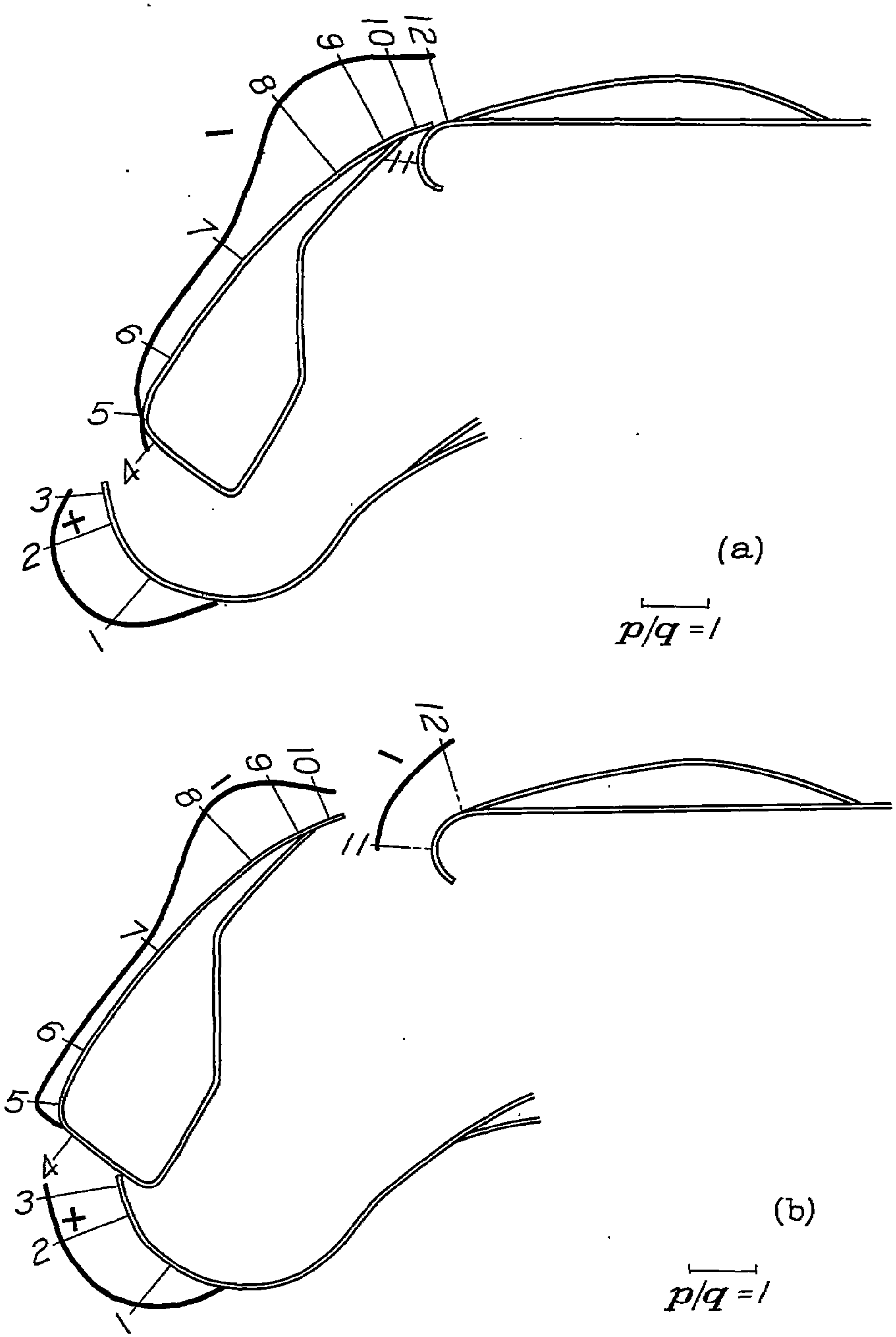


Figure 9.- Smoke flow being introduced ahead of the propeller.
Nose-slot cowling 3-C.



Figures 11a,11b.- Pressure distribution over nose-slot cowling 3-C. Level flight. (a) High-speed position. (b) Low-speed position.

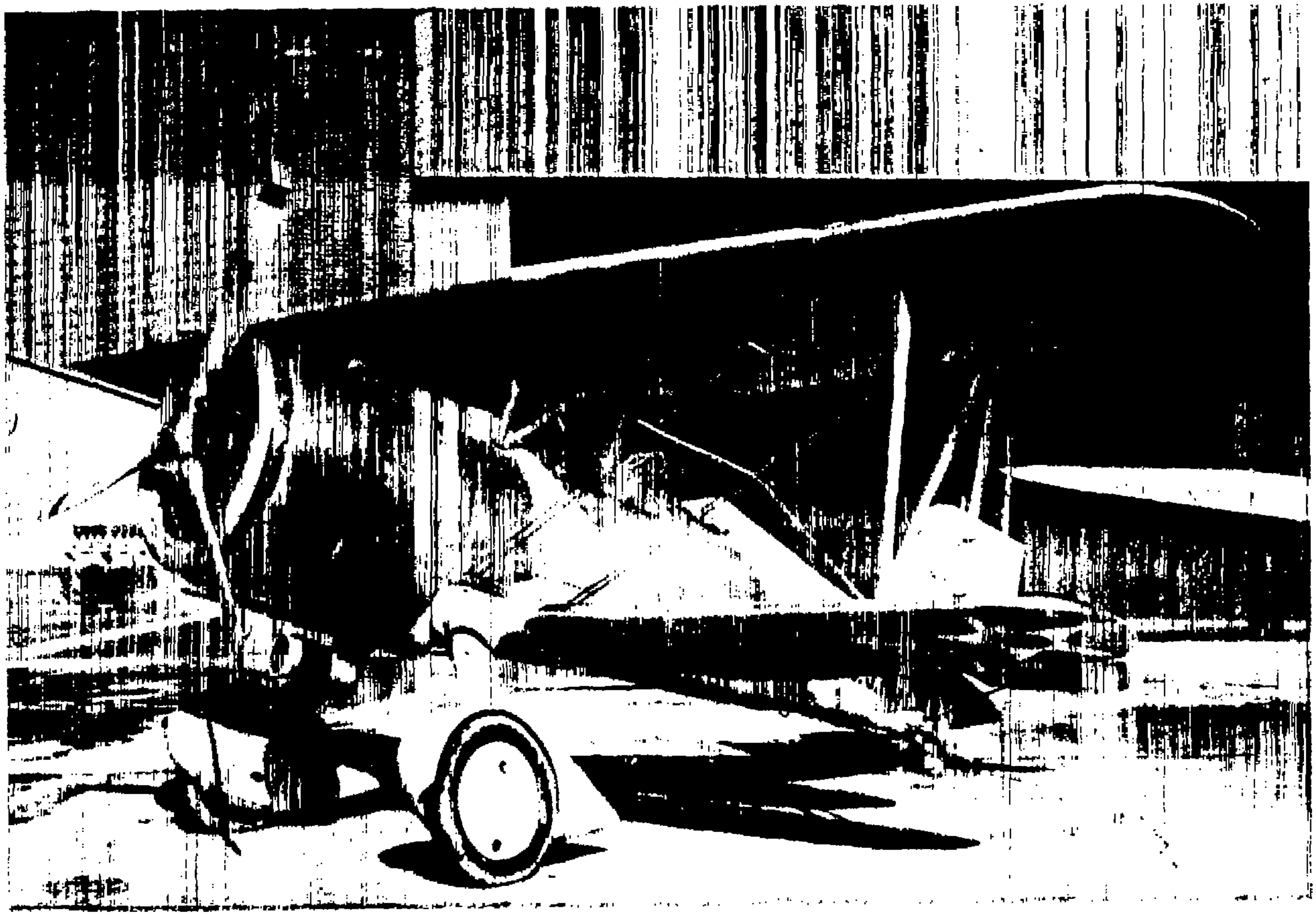


Figure 12.- The BFC-1 airplane equipped with nose-slot cowling 4-A in the low-speed position.

Figure 13a.- Close-up of nose-slot cowling 4-A in the low-speed position. Square-edge disk in place.

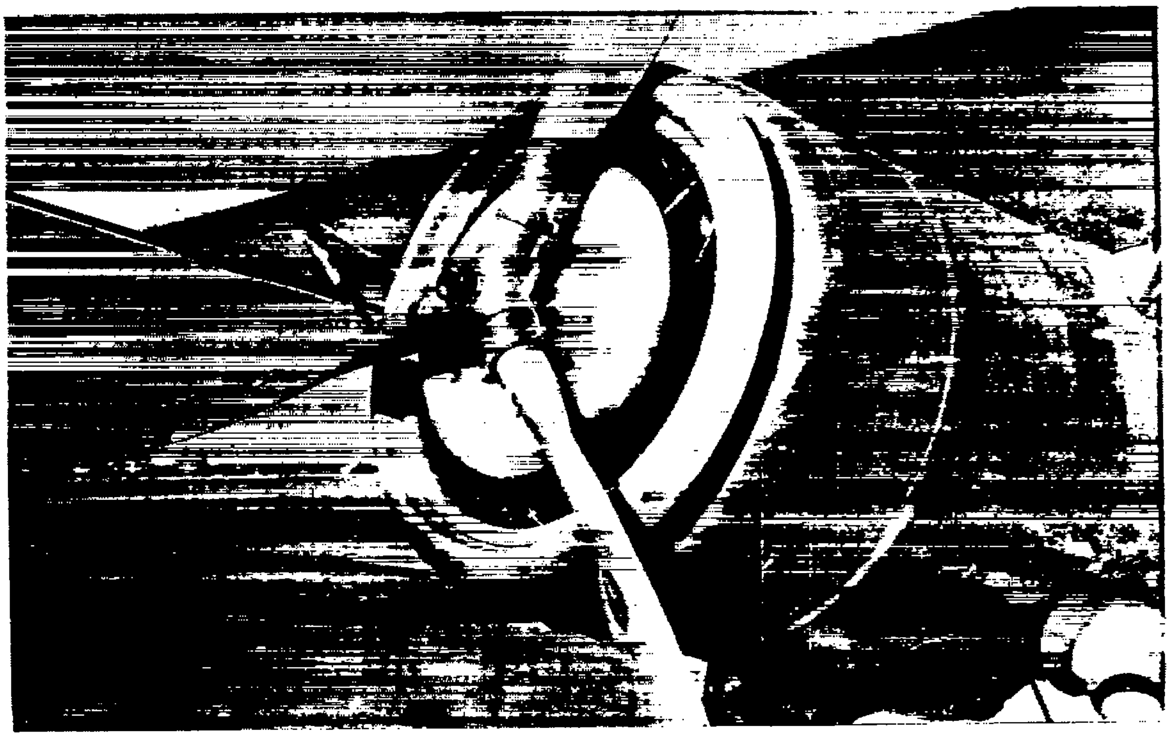


Figure 13b.- Close-up of nose-slot cowling 4-A in the low-speed position. Round-edge disk in place.

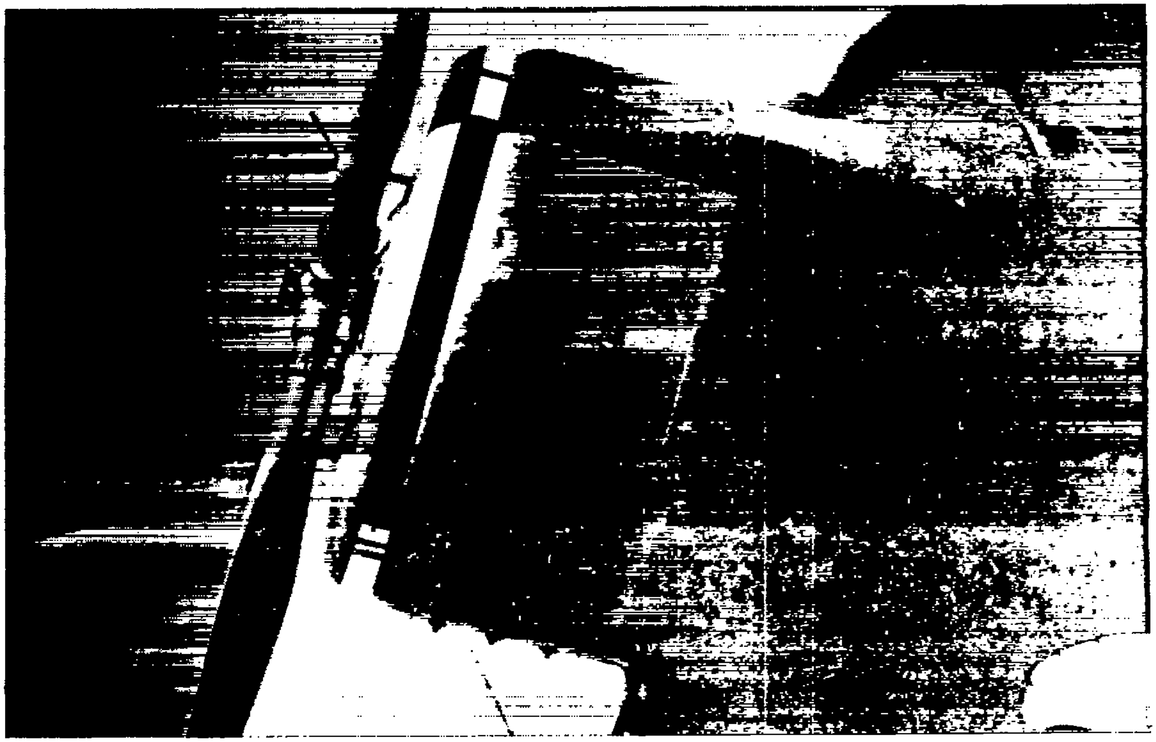


Figure 14a.- Side view of nose-slot cowling 4-A. Low speed position.

Figure 14b.- Side view of nose-slot cowling 4-A. High-speed position; round-edge disk in place.

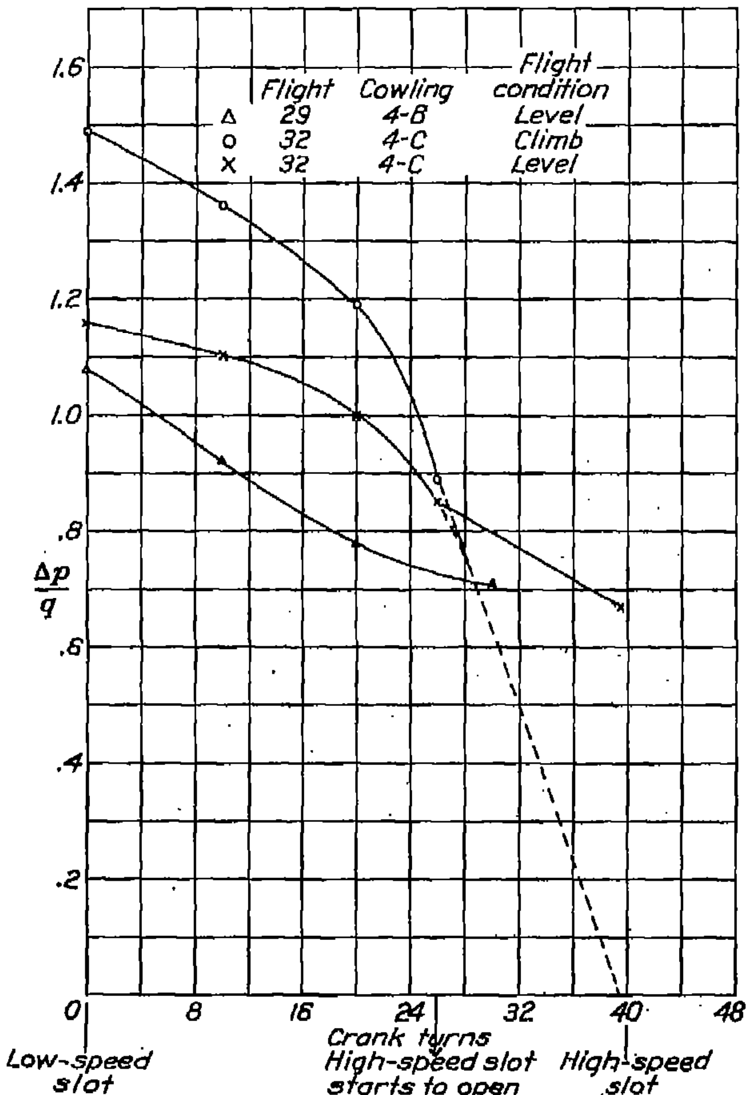


Figure 15.- Variation of $\Delta p/q$ in flight with cowling position for nose-slot cowlings 4-B and 4-C.

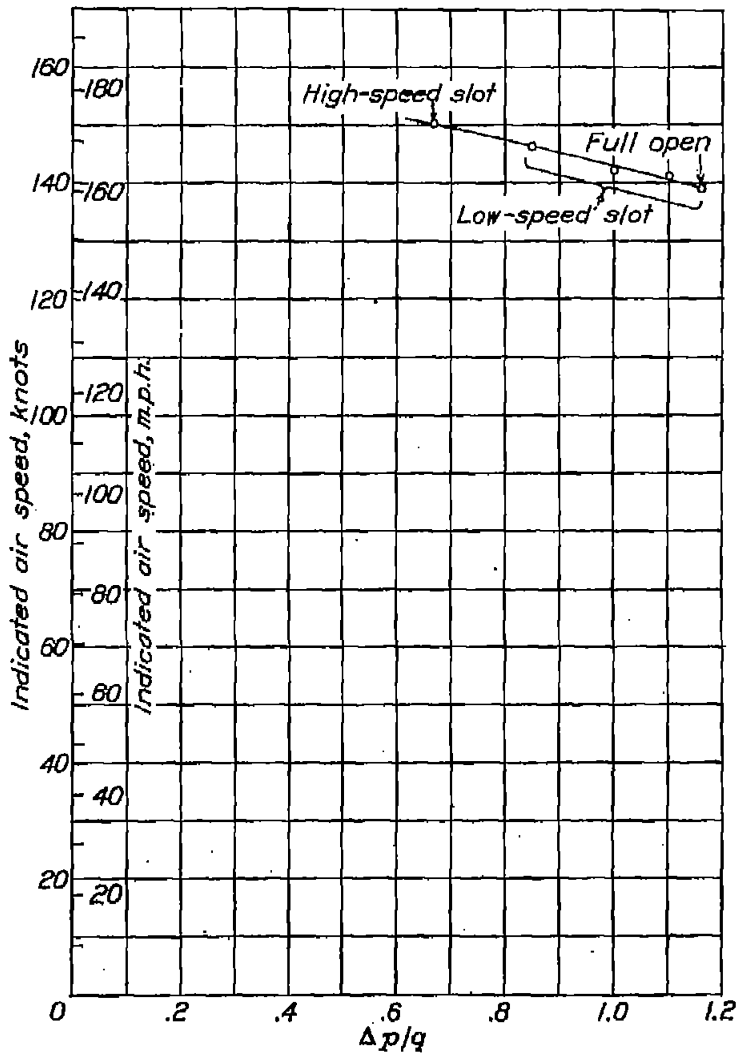


Figure 16.- Variation of air speed with $\Delta p/q$ for the constant-power level-flight condition as obtained with nose-slot cowling 4-C.

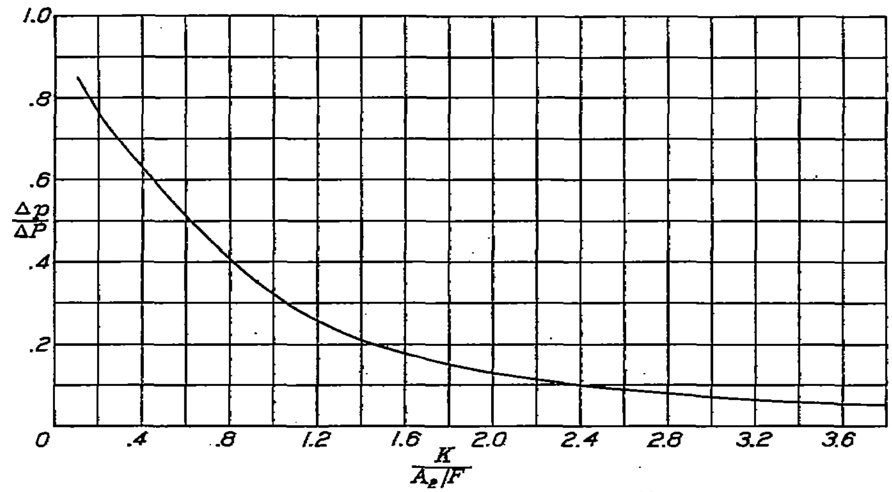


Figure 18.- Variation of $\Delta p/\Delta P$ with $\frac{K}{A_2/F}$ (reference 2).

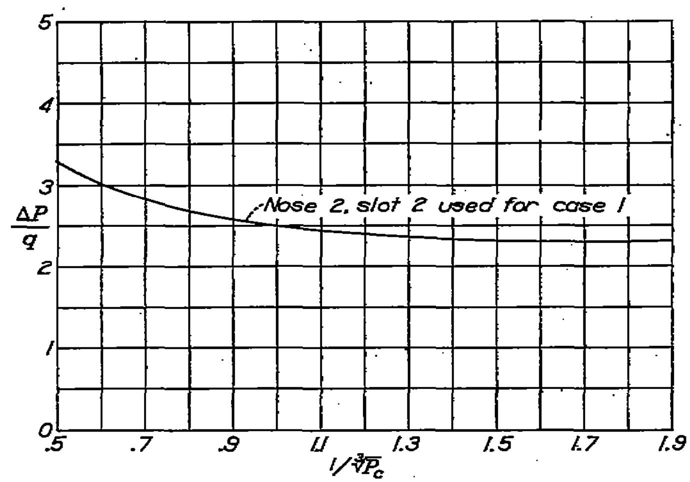


Figure 17.- Variation of $\Delta P/q$ with $1/\sqrt[3]{P_c}$ (reference 2).

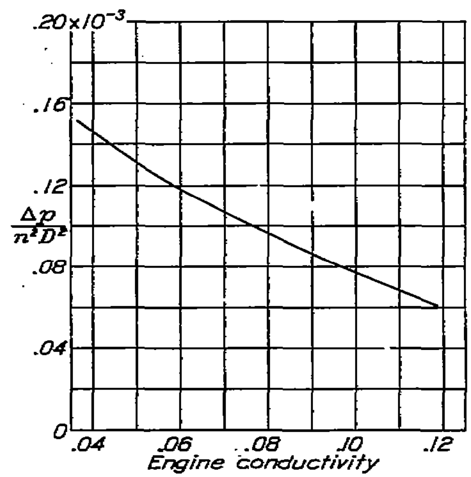


Figure 19.- Variation of $\Delta p/n^2D^2$ with engine conductivity (reference 2).